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ORIGINAL ARTICLE

Heart rate variability and pre-competitive anxiety in BMX discipline

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Abstract Altered neural mechanisms implying autonomic functioning have been described related to anxiety. Pre-competitive stress may be considered as an anxiety-state associated with disorders (i.e. somatic and cognitive alterations, and self-confidence worsening) that severely impair sport performance, conditioning short-lasting strength-related disciplines like BMX. From the psychological perspective, coaches use questionnaires like CSAI-2R to identify these alterations. However, with the emergence of psycho-physiological and non-linear approaches, recent studies suggest that HRV analysis provides a non-invasive tool to assess them. Hence, our purpose was to analyze how BMX competition affects subjective perception of anxiety, and if this emotional alteration is reflected in HR dynamics, analyzed both linear and nonlinearly, exploring the evolution of this relationship in a 2-day competition. Eleven male athletes from the BMX Spanish National Team were assessed from baseline HRV the morning of a training session (rT) and on two successive days of competition (rC1 and rC2), repeating HRV recording with CSAI-2R 20 min prior to training (aT) and competition (pre-competitive: aC1 and aC2). Repeated measures MANOVA showed significant vagal slow-down responses in aC1 and aC2 comparing not only with aT, but also comparing with rT, rC1 and rC2, coinciding with significant greater scores for the somatic and cognitive anxiety (SA and CA) in aC1 and aC2 versus aT. Pearson analysis showed a large and positive correlation between $\alpha 1$ and SA in C1, and close to it between SampEn and CA in aC2; both were confirmed by Bland–Altman chart analysis. Our results confirm that HRV analysis provide a complementary tool to assess competitive pressure.

Keywords Autonomic nervous system · Vagal modulation · CSAI-2R · Non-linear analysis · Psychophysiological approach · Cycling

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Introduction

Dealing with competitive pressure is an integral part of participation in high-performance sport. Traditionally, high levels of anxiety in competitive situations have been described in sport people of any age and category (Gould et al. 1983; Rushall 1979; Scanlan and Passer 1979; Sonstroem 1984) with great evidence on the negative effects that this anxiety may have upon performance (Rushall 1979; Weinberg and Genuchi 1980). More recently, some authors have been using the Hanin Model to explain the relation between pre-competitive anxiety, psychophysiological and sociological state, and sport performance (Davis and Cox 2002; Hagtvet and Hanin 2007), advocating for the existence of an individual zone of stress, IZOF (individual zone of optimal functioning) (Hanin 2000, 2003), within which athletes reduce emotional overload influence on performance. Furthermore, the development of some questionnaires like the CSAI-2 "Competitive State Anxiety Inventory-2"(Martens et al. 1990), have helped to elucidate between the different factors related to anxiety: cognitive anxiety, somatic anxiety and self-confidence; greatly contributing to the assessment and better understanding of the athletes pre-competitive anxiety (Woodman and Hardy 2001).

The bicycle motocross (BMX) sport, Olympic discipline since Beijing 2008, is not an exception, with already described high levels of perceived pre-competitive anxiety (Som et al. 2009), in line with previous studies that have pointed to high prevalence of somatic anxiety in short-time disciplines, more dependent on explosive strength resources (Hanton et al. 2000; Kleine 1990). Moreover, BMX competition involves itself a high degree of uncertainty as decision-making processes are somehow influenced by opponents' actions, tracks design remain unknown, and any mistake may lead to falls and irretrievable time losses (Zabala et al. 2009; Mateo et al. 2011); hence, anxiety seems to play a key role in BMX. Therefore, although some suitable levels of anxiety may be required, a proper handling on this mood state seems to be of importance to successfully copy competition (Wilson et al. 2007).

Accordingly, pre-competitive anxiety may be considered an specific state anxiety associated with the general responses and activation of the organism in situations of competition (Martens et al. 1990), thus related to autonomic nervous system (ANS) functioning, and more specifically to the sympathetic nervous system (SNS). From a psychophysiological point of view, authors such as Lane et al. (1992) and Berntson et al. (1997) coincide in that heart rate variability (HRV), mainly modulated by the ANS (Montano et al. 2009), is sensitive to changes in the emotional state, and suggest its usage as an analysis technique for identifying the interaction between the heart and the brain. Similarly, some recent studies have highlighted the fact that the analysis of HRV and its connection with anxiety may provide a useful field-based assessment tool (Friedman 2007; Servant et al. 2009): finding associations in different real stressful situations such as before an oral exam (Fuller 1992) or immediately prior to a lecture (Filaire et al. 2010). At the same time, some clinical investigation point at a reduction in HRV in anxiety-related phenomena; and several are the essays that examine the different levels of HRV in patients with different general anxiety disorders, i.e. in their childhood, social and specific phobias, or panic (Cohen et al. 2000; Thayer et al. 2000; Mauss and Gross 2004; Yeragani et al. 2004; Scheeringa et al. 2008). Other essays point at HR dynamics analysis as a tool to predict the mortality risk due to cardiac disorders in patients with anxiety, depression and nervous breakdown (Blasco-Lafarga et al. 2010; Martens et al. 2007). In fact, psychophysiology perspectives like the "polyvagal theory" (Porges 2001, 2003, 2007, 2009) deep on holistic and systemic approaches which relate autonomic function to behavior, and provide a wide and dynamic theoretical framework to support this crossroad of disciplines.

However, although there is broad agreement about the anxiety's influence on motor learning processes in effort situation (Wilson et al. 2007), the relationship between HRV and state anxiety has been barely studied in sport competition. Mullen et al. (2005) found that artificially augmented state anxiety was related to poorer HRV responses during a golf putt task; however, Cooke et al. (2010) failed to show a significant reduction in vagal activity (i.e., *r*MSSD) with increased pressure conditions in the same task. Closer to real competition, during a chess game, a legitimate psychological stress environment, a pair of studies assessing HRV have been conducted. In the former, Schwarz et al. (2003) showed an association between increasing helplessness/hopelessness ratio and reduced vagal activity; whereas in the latter Troubat et al. (2009) suggested a stimulation of the sympathetic branch with no changes in parasympathetic activity during chess game. Only one study, to the best of our knowledge, has previously used HRV to explore cardiac autonomic regulation in the moments prior to competition; finding a shift towards sympathetic predominance as a result of decreased parasympathetic activity, and suggesting HRV as a valid, practical and non-invasive way to assess changes in sympathetic–parasympathetic balance in the presence of competitive stress (Cervantes Blásquez et al. 2009).

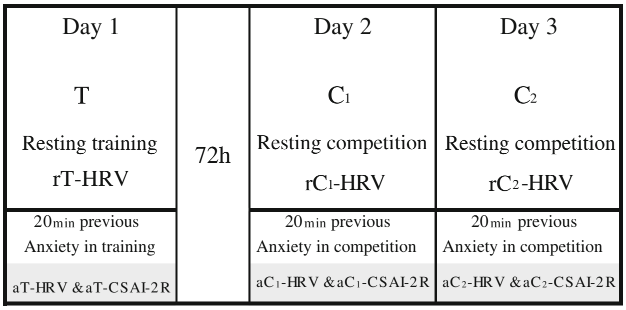
From a methodological point of view, the emergence of nonlinear approaches has allowed us to delve into HR dynamics behavior, providing us with a complementary qualitative view (Goldberger et al. 2000; Penttila et al. 2003). Specifically in anxiety disorders field, complexity measures could be a useful diagnostic tool (Bornas et al. 2006). Moreover, jointly with fractal analysis, complexity measures seem to offer even a deeper insight into cardiac autonomic functioning (Blasco-Lafarga et al. 2010). On the other hand, the development of the "Revised Competitive State Anxiety Inventory-2" (CSAI-2R), proposed by Cox et al. (2003) as an upgrade to the pioneering "Competitive State Anxiety Inventory-2" (CSAI-2) (Martens et al. 1990), has facilitated state anxiety assessment in real competition situations.

Therefore, the aim of our study is to evaluate how BMX competition affects subjective perception of anxiety, and assess if this emotional alteration is reflected in HR dynamics, analyzed both linear and nonlinearly. Moreover, we challenged to explore how this relationship may evolve during two consecutive competitive days. We hypothesize that state anxiety generated by the BMX competition significantly alters cardiac autonomic functioning, thus affecting HR dynamics. Therefore, the analysis of these alterations may help athletes and coaches to train and improve such responses in future competitions. Following previous studies, we also hypothesize that nonlinear approaches, less polluted by changes in the external environment (Mäkikallio et al. 2001), may reflect more accurately these field-based anxiety-related changes in HR behavior.

Methods

Experimental design

The study consisted of two parts. Figure 1 presents a schematic view of the experimental protocol. Firstly, it created a simulated competition, during an ordinary training day [T], aimed at proportioning a stressful situation. Afterward, 72 h later, subjects were assessed during a 2-consecutive day real BMX competition [C_1] and [C_2]. Each of the 3 days HR was recorded during 10 min in both resting baseline condition [r] and anxiety precompetitive condition [a]. In the former subjects were tested just after awakening, before having breakfast (rT, rC_1 and rC_2); whereas the latter testing was performed 20 min before the beginning of the simulated or real competition (aT, aC_1 and aC_2), immediately after filling-out the CSAI-2R questionnaire. In both cases, subjects were seated and asked to remain still, without speaking or doing disruptive movements of the head or hands throughout the recording period. Seated position was primarily chosen because we wanted to interfere as less as possible in the athletes' standardized precompetitive routine and lying supine 20 min before a competition would have been rather unusual for them. We acknowledge the experimental bias it implies (i.e., differences in central baroreceptors loading); notwithstanding, sitting position is generally associated with intermediate HRV levels and indeed, at low HR levels (more probably occurring in a lying supine position), saturation of HRV—expressed as unchanged or even decreased HRV despite increased cardiac vagal outflow—is susceptible of appearing (Kiviniemi et al. 2004). Moreover, prior to examining possible relationships between CSAI-2R scores and HR dynamics at anxiety condition, each subject response was individualized in relation to his resting values, thus removing any possible confounding bias introduced by using a seated position. Finally, unlike some recent investigations, since precompetitive assessment was conducted in the field, respiratory rate was not controlled (Buchheit et al. 2010).



Day 1		Day 2	Day 3
T Resting training rT-HRV	72h	C_1 Resting competition rC_1-HRV	C_2 Resting competition rC_2-HRV
20min previous Anxiety in training aT-HRV &aT-CSAI-2R		20min previous Anxiety in competition aC_1-HRV &aC_1-CSAI-2R	20min previous Anxiety in competition aC_2-HRV &aC_2-CSAI-2R

Fig. 1 Experimental protocol

Participants

Eleven male cyclists from the Valencian and Andalucian autonomic teams took part in the study. Unfortunately, only five of them could be tested of the baseline HR dynamics in the training condition (rT). All the athletes were of high national performance level, had a competitive experience of 6 ± 1 years and trained 3 ± 1 h a day. The descriptive characteristics of the subjects are presented in Table 1. Both the filling-out of the CSAI-2R questionnaires and the HR recordings were carried out in compliance with the Declaration of Helsinki and participants gave voluntary written consent to participate in the investigation, which was previously approved by the ethics committee of the University of Valencia. Data were collected during a training camp jointly organized by the Valencian and Andalucian autonomic teams, the week before the beginning of 2009 BMX Spanish Championship. All the athletes had been summoned by their respective autonomic teams, thus assuring that tapering prior to competition, resting hours, food intakes, hydration and supplementation were homogeneous and accurately controlled.

Instruments

The CSAI-2R, proposed by Cox et al. (2003) as an upgrade to the CSAI-2 (Martens et al. 1990), was used to measure precompetitive state anxiety. Based on findings of improved factorial validity showing acceptable model fit

Table 1 Descriptive data (mean ± SD) of anthropometric characteristics

	Average $n = 11$
Age (years)	19.3 ± 2.1
Weight (kg)	72.2 ± 10.37
Height (cm)	179.2 ± 5.12
Fat-free mass (Martin) (kg)	58.08 ± 1.17
Fat mass (Faulkner) (%)	11.5 ± 1.36
Body Mass Index (kg/m^2)	22.51 ± 3.23

when evaluated with confirmatory factor analysis (CFI = 0.95, NNFI = 0.94 and RMSEA = 0.05), the CSAI-2R has been found to be more psychometrically sound than the original version of the CSAI-2 (Cox et al. 2003). The Spanish version comprises 18 items distributed in three hypothetical subscales: somatic anxiety (SA, eight items), cognitive anxiety (CA, five items) and self-confidence (SC, five items). Each item is presented with a four Likert-type response options numbered from 1 ("not at all") to 4 ("very much so"). Therefore, scores in each of the three subscales may range as follows: SA (from 8 to 32), CA (from 5 to 20), SC (from 5 to 20). Research using this translation indicates that it possesses psychometric properties consistent with the English version, in terms of both its dimensionality and internal consistency (cronbach alpha coefficients for the factors ranged from 0.79 to 0.83) (Andrade Fernandez et al. 2007).

HR measurements were performed using a Polar RS800 HR monitor set to R-R interval mode (Polar Electro, Kempele, Finland) together with an electrode transmitter belt (T61), after application of conductive gel as recommended by the manufacturer. This instrument has been previously validated for the accurate measurement of R-R intervals and for the purpose of analyzing HRV (Gamelin et al. 2006; Nunan et al. 2009). Data were transferred to Polar Pro Trainer 5 software (Polar Electro, Kempele, Finland) and each downloaded R-R interval file was then further analyzed by means of Kubios HRV Analysis Software 2.0 (The Biomedical Signal and Medical Imaging Analysis Group, Department of Applied Physics, University of Kuopio, Finland).

HR data processing

The whole analysis process was carried out by the same researcher to ensure consistency. After estimating the trend of the R-R interval series, artifact beats were identified as R-R values deviating more than 0.25 s from this baseline, as recommended by the manufacturer, and subsequently piecewise cubically interpolated. In every subject, artifact beats accounted for less than 1%. Analyses were then performed on the last 5-min segment to insure stableness of the data. For the time domain, the mean RR interval (RRi), the standard deviation of normal RR intervals (SDNN) and the root-mean-square difference of successive normal R-R intervals (*r*MSSD) were calculated. Prior to power frequency analysis, RR data were detrended (Smooth priors, $\lambda = 500$) (Tarvainen et al. 2002) and resampled at 4 Hz. The Fast Fourier Transform spectrum was then calculated using a Welch's periodogram method. Low-frequency power (LF, 0.04–0.15 Hz), high-frequency power (HF, 0.15–0.4 Hz) were calculated as integrals of the respective power spectral density curve. LF/HF ratio was also retained for statistical analysis.

Moreover, detrended fluctuation analysis (DFA) technique (Peng et al. 1995) was applied to the R-R interval data in order to quantify self-similarity correlations. Briefly, the root-mean square fluctuation of the integrated and detrended data are measured in observation windows of different sizes and then plotted against the size of the window on a log–log scale. The result of this calculation is the scaling exponent α, which represents the slope of this line and relates (log) fluctuation to (log) windows size. Typically, in DFA the correlations are divided into short-term and long-term fluctuations. Based on previous research (Mendonca et al. 2010; Millar et al. 2009), and because of our relatively short recording time, we decided to utilize the short-term (4–16 beats) scaling exponent (α_1) to analyze our R-R interval data. Eventually, sample entropy (Richman and Moorman 2000) was calculated to provide a general indication of predictability of the time-series. By definition, SampEn is the negative natural logarithm of an estimate for the predictability in finding specific matches in a short time-series. To characterize the stringency of match recognition, the length (m) of the subseries and the tolerance (r) of the matches are previously set. Those adjustable parameters were fixed at $m = 2$ and $r = 20\%$ of the SD of the datasets, as previously described in the literature (Hautala et al. 2010; Millar et al. 2010).

Statistical analyses

The Statistical Package for the Social Sciences software (SPSS version 15.0, SPSS Inc., Chicago, USA) was used for the analysis and treatment of the data. The distribution of each variable was examined with the Kolmogorov–Smirnov normality test. When data were skewed, as it was the case for HF and LF measures, data were transformed by taking the natural logarithm to allow parametric statistical comparisons that assume a normal distribution. Therefore, those two variables will henceforth be referred as lnHF and lnLF, respectively.

A two-way repeated measures MANOVA [2 (days of testing) × 2 (sampling conditions)] was used to compare HR dynamics indices among the whole sample (11 subjects). Meanwhile, a two-way repeated measures MANOVA [3 (days of testing) × 2 (sampling conditions)] was applied for the 5 subjects who were tested in both training and competition experimental conditions. Regarding anxiety registers, a one-way repeated measures MANOVA was employed to assess differences in CSAI-2R scores between the three days ($n = 11$). Where a significant interaction was found, Bonferroni post hoc test was performed to determine where the differences rested. Sphericity was assessed by means of Mauchly's test, and whenever the test was violated, necessary technical corrections were performed using the Greenhouse-Geisser test.

Pearson's correlations analyses were performed to examine possible relationships between CSAI-2R scores and HR dynamics at anxiety condition (aC_1 and aC_2). As values of HRV indices seem to be highly individual (Martinmaki et al. 2006), values at resting baseline condition [r] for each subject were set as 100% and anxiety [a] ones expressed in relation to this individual 100% value. Several studies have used similar procedures (Hynynen et al. 2010; Pichot et al. 2002). The magnitudes of correlations were defined according to Cohen (1988), whereby correlations >0.5 are considered large, 0.3–0.5 are considered moderate and 0.1–0.3 are considered small. Whenever a significant correlation was noted, linear regression and Bland–Altman analyses (using MedCalc 11.3 statistical software package) were applied. In the latter, as the units of CSAI-2R and HR dynamics measures were not the same, prior to Bland–Altman plotting values were transformed into *Z*-scores. For all analyses, a *p* value of <0.05 was considered statistically significant. Data are presented as means and standard deviations (±SD).

Results

Precompetitive anxiety analysis

Repeated measures one-way MANOVA showed a main effect for day of testing on SA and CA components ($p < 0.001$) and also on SC ($p < 0.01$). Further Bonferroni pairwise adjustments showed that both aC_1 and aC_2 scores were higher than aT scores for CA and SA subscales of CSAI-2R questionnaire ($p < 0.005$ between C_1 and T; $p < 0.05$ between aC_2 and aT); and lower for SC ($p < 0.05$). When comparing the 2 days of competition, pairwise comparison showed that both CA and SA were higher in aC_1 (13.30 ± 4.27 vs. 11.40 ± 4.09; 20.60 ± 7.11 vs. 17.30 ± 6.50; p < 0.01); while SC did not differ significantly between aC_1 and aC_2. Pearson correlation analyses between the three anxiety components showed a large and positive correlation between SA and CA in aC_1 ($r = 0.774$; $p < 0.05$), which was blunted, however, in aC_2. Meanwhile, SC did not correlate either with CA or SA during neither aC_1 nor aC_2. Results of precompetitive anxiety analysis are presented in Table 2 and Fig. 2.

Table 2 Descriptive statistics (mean ± SD) of CSAI-2R subscales scores

	CSAI-2R		
	Cognitive	Somatic	Self-confidence
Anxiety			
aT	6.73 ± 1.19	8.64 ± 0.67	17.91 ± 1.70
aC_1	13.30 ± 4.27^1	20.60 ± 7.11^1	15.00 ± 2.71^1
aC_2	11.40 ± $4.09^{1,2}$	17.30 ± $6.50^{1,2}$	16.50 ± 2.59

[1] Significantly different from aT condition ($p < 0.05$)

[2] Significantly different from aC_1 condition ($p < 0.05$)

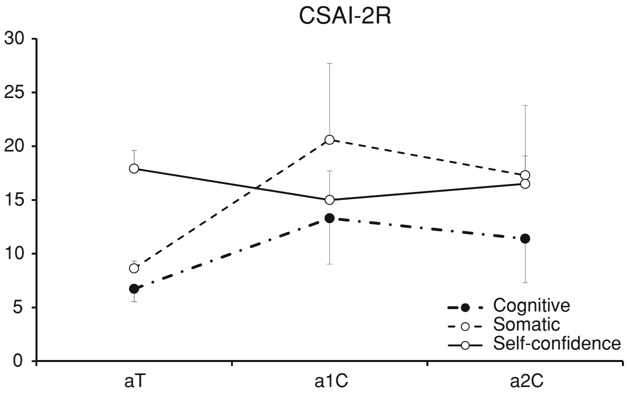


Fig. 2 CSAI-2R subscales scores during the 3 days of testing

HR dynamics results

Table 3 shows values of linear and nonlinear HR dynamics indices in each of the six experimental conditions. Repeated measures two-way MANOVA ($n = 11$) showed a main effect for sampling condition (r vs. a) along the following HR dynamics indices: RRi, SDNN, *r*MSSD, lnHF, LF/HF, α_1 ($p < 0.01$); lnLF ($p < 0.05$). However, no significant day effect or interaction for day and sampling condition effect were noted. Further pair-wise Bonferroni comparisons revealed significant differences between rC_1 and aC_1 measurements in the following indices: RRi, SDNN, *r*MSSD, lnHF, LF/HF, SampEn and α_1 ($p < 0.01$). Similarly, significant differences between rC_2 and aC_2 measurements were found in the following variables: RRi, SDNN, *r*MSSD, lnHF SampEn and α_1 ($p < 0.01$), lnLF and LF/HF ($p < 0.05$). Eventually, RRi significantly differed between aC_1 and aC_2 ($p < 0.05$).

Besides, further analysis uniquely considering subjects who were also tested during training condition ($n = 5$) added some relevant information. Respecting sampling condition, no significant differences were found in any of the HR dynamics indices analyzed between rT and aT measurements. On the contrary, regarding day condition, significant differences between aT and both aC_1 and aC_2 were found in the following variables: RRi ($p < 0.01$); SDNN and *r*MSSD ($p < 0.05$). Moreover, three other indices significantly differed between aT and aC_1: SampEn ($p < 0.01$); lnHF and α_1 ($p < 0.05$). Eventually, no significant differences between rT, rC_1 and rC_2 were found in

Table 3 Descriptive statistics (mean ± SD) of linear and nonlinear HR dynamics indices

	Time domain analysis			Frequency domain analysis			Nonlinear analysis	
	RRi	SDNN	*r*MSSD	lnLF	lnHF	LF/HF	α_1	SampEn
Basal								
rT ($n = 5$)	1026.54 ± 136.67	68.37 ± 14.00	72.17 ± 35.66	7.83 ± 0.35	7.77 ± 0.53	1.53 ± 0.82	1.10 ± 0.33	1.3 ± 0.16
rC_1 ($n = 11$)	931.39 ± 148.97	50.57 ± 21.59	45.59 ± 23.38	6.66 ± 1.18	6.35 ± 1.24	1.64 ± 1.29	1.27 ± 0.13	1.36 ± 0.39
rC_2 ($n = 11$)	939.03 ± 122.76	68.69 ± 29.30	62.44 ± 34.97	7.52 ± 1.24	6.78 ± 1.54	2.39 ± 1.26	1.19 ± 0.26	1.18 ± 0.37
Anxiety								
aT ($n = 5$)	951.28 ± 112.05	67.14 ± 19.21	74.51 ± 28.14	7.48 ± 0.43	7.58 ± 0.58	1.24 ± 0.65	1.01 ± 0.15	1.34 ± 0.2
aC_1 ($n = 11$)	568.67 ± 72.58^{1,3}	27.01 ± 13.12^{1,3}	15.37 ± 10.45^{1,3}	5.89 ± 1.17	4.12 ± 1.42^{1,3}	6.64 ± 3.19^{1}	1.61 ± 0.14^{1,3}	0.79 ± 0.23^{1,3}
aC_2 ($n = 11$)	600.29 ± 71.71^{2,3,4}	25.17 ± 13.47^{2,3}	13.84 ± 9.43^{2,3}	5.70 ± 1.30^{2}	3.97 ± 1.13^{2}	7.31 ± 5.19^{2}	1.61 ± 0.17^{2}	0.83 ± 0.23^{2}

RRi mean R-R intervals, *SDNN* standard deviation of R-R intervals, *rMSSD* root-mean-square difference of successive R-R intervals, *lnLF* low-frequency power of R-R intervals, *lnHF* high-frequency power of R-R intervals, *LF/HF* ratio of low-frequency to high-frequency power, α_1 short-term fractal scaling exponent, *SampEn* sample entropy

[1] Significantly different from their respective [r] condition (i.e., rC_1 condition) ($p < 0.05$)

[2] Significantly different from their respective [r] condition (i.e., rC_2 condition) ($p < 0.05$)

[3] Significantly different from aT condition ($p < 0.05$)

[4] Significantly different from aC_1 condition ($p < 0.05$)

any HR dynamics variable. Figure 3 shows SampEn and α_1 behavior during [a] condition throughout the 3 days of testing.

Correlations between CSAI-2R scores and HR dynamics

Pearson correlation analyses were conducted in order to assess possible relationships between anxiety and changes in physiological parameters (from resting to anxiety condition) during the 2 days of competition. Analyses revealed that both time (RRi, SDNN, *r*MSSD) and frequency domain indices (lnLF, lnHF, LF/HF) were uncorrelated with CSAI-2R subscales scores (CA, SA, SC). However, a large and positive correlation was found between α_1 and SA in C_1 ($r = 0.72$, $p < 0.05$); where consequently, SA explained 51.8% of α_1 variance. This relationship got lost in C_2, but a nearly significant correlation emerged between SampEn and CA ($r = 0.603$; p = 0.065). Moreover, Bland–Altman analysis showed acceptable bias and limits of agreement in both relationships (i.e., between α_1 and SA in C_1, between SampEn and CA in C_2) (see Figs. 4, 5). SC did not correlate either with linear or nonlinear HR dynamics indices during neither C_1 nor C_2.

Discussion

Sympathetic alterations, together with other altered neural mechanisms implying different structures and functioning of the nervous central system (NCS), have been broadly described related to fear, and therefore to anxiety responses (see Friedman 2007 for review). Notwithstanding, “Neurovisceral integration model” (Friedman 2007) points to a reduced vagal tone in anxiety as a main adaptive inhibition mechanism affected by anxiety severe disorders as well as anxiety-state forms. Hence, anxiety implies multiple physiologic pathways, and so needs a complex approach in

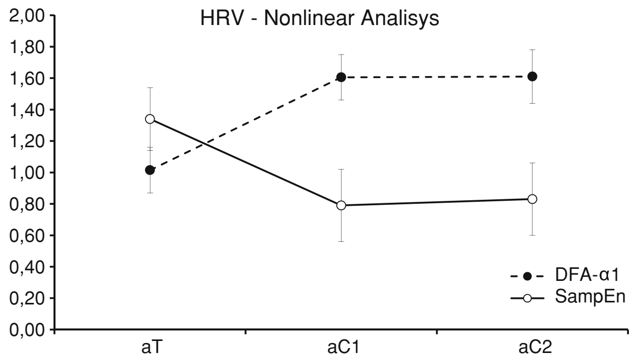


Fig. 3 SampEn and α_1 behavior during anxiety condition throughout the three days of testing

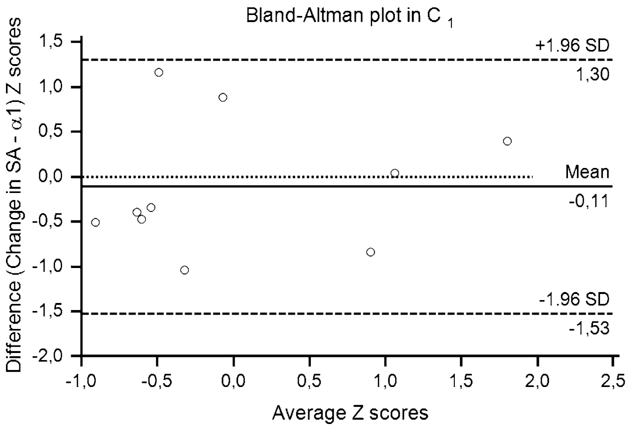


Fig. 4 Bland–Altman analysis between SA and α_1 variables

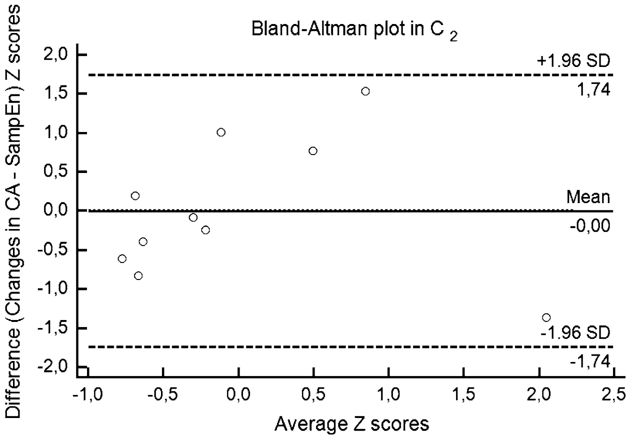


Fig. 5 Bland–Altman analysis between CA and SampEn variables

its assessment and valuating. In this context, HR dynamics analysis seems to provide a useful insight, due to its ability to assess the instantaneous slowing down vagal control. In line with these complex approaches, the main finding in our study confirms that significant changes in HRV indices due to pre-competitive anxiety alterations measured just before the BMX competition, similarly to some recent studies in other disciplines (i.e. swimmers) (Cervantes Blásquez et al. 2009). This result coincides with significantly greater scores for the somatic and cognitive anxiety sub-scales, accompanied by lower self-confidence scores, in the competition registers of the CSAI-2R inventory when compared to the training condition ones. According to the abovementioned results, it may be stated that both HR dynamics and CSAI-2R reflected pre-competitive anxiety alterations. This statement is moreover based on a pair of further analyses.

Considering that the autonomic nervous system regulates the cardiovascular system by concomitant changes of vagal and sympathetic branches, and that many HR dynamics indices reflect different aspects of this complex regulatory system, by assessing their evolution regarding to sample condition, we found that all the indices measured, except from lnLF, significantly changed from resting condition to pre-competitive condition during the two competition days (aC1 vs. rC1 and aC2 vs. rC2). Accordingly, knowing that both recordings were made in a seated position thus removing a possible body posture effect (Buchheit et al. 2009), it may be thought that mental stress caused by competition proximity would have been the main responsibility for HR dynamics imbalance. This would be in agreement with several previous studies reporting HR dynamics alterations due to fear and anxiety feelings prior to a mental stress situation (Filaire et al. 2010; Fuller 1992). Notwithstanding, it may be also argued that these differences may have been solely due to the sympathetic activation necessary to ensure anticipatory metabolic and cardiovascular responses to a physical effort. However, no significant differences were found in any HR dynamics index from aT to rT; therefore, pre-competitive anxiety exposure and not physical exercise immediacy per se seems to play the key role in HR dynamics imbalance recorded prior to a BMX competition.

Similarly, CSAI-2R inventory showed the effect of real competition on state anxiety. Moreover, CSAI-2R scores for both SA and CA during competition condition (see Table 3) were considerably larger compared to those recently measured in country skiers and swimmers (Lundqvist et al. 2010). Two factors could explain this difference. On the one hand, anxiety responses are known to be importantly related to the type of the task and the rate of uncertainty (Hanton et al. 2000; Martens et al. 1990; Matheson and Mathes 1991), and BMX competition, compared to swimming and country ski ones, is short time-lasting, more dependent on explosive strength resources and probably involves itself a higher degree of uncertainty. Indeed, Veldhuijzen Van Zanten et al. (2002), in a laboratory setting study (a motorized racing car game), showed that *dual* races, compared to *solo* races, caused a greater decrease in *r*MSSD, an anxiety-related index of HR dynamics. Although swimming and country ski could not be obviously consider *solo* races, it could be agreed that decision-making processes are less influenced not only by opponents' actions, but also by environment or track design, than BMX competition. On the other hand, in Lundqvist et al. (2010) study participants completed CSAI-2R 45 min before the beginning of their competitive event, whereas in our study CSAI-2R questionnaires were filled-out 20 min prior to the races. Hanin (2000) already noted that from 1 h before performance anxiety levels are significantly elevated, but probably even within this immediate 1 h prior to the competition important differences in anxiety perception may be seen (Mellalieu et al. 2008).

HR dynamics data obtained in aC_1 condition (see Table 3) evidenced a cardiac autonomic imbalance. Absolute linear indices (RRi, SDNN, *r*MSSD, lnLF, lnHF) showed greatly reduced values, whereas LF/HF ratio significantly increased from rC_1 to aC_1 condition. Although the indirect nature of HR dynamics analysis calls for caution in inferring autonomic regulation, reduced absolute linear indices point to a slowing down vagal control—as all of them has been proven to reflect mainly vagal activity (Martinmaki et al. 2006)—whereas augmented LF/HF ratio suggests an enhancement in sympathetic activity. Moreover, when qualitatively analyzed HR dynamics by means of nonlinear methods (see Fig. 3) SampEn showed a significant increase in signal regularity (reduced SampEn values) and α_1 evidenced a loss of fractality toward a strongly correlated signal. This picture acutely resembles the one observed after vagal blockade with glycopyrrolate (Penttila et al. 2003). Therefore, nonlinear methods reinforce linear HRV results, confirming a reciprocal interplay between sympathetic and vagal control of HR during pre-competitive anxiety situations, by which sympathetic activity enhancement was accompanied by a decrease in vagal modulation (Hautala et al. 2003; Mourot et al. 2007; Tulppo et al. 2005). Besides, the large and positive correlation displayed between α_1 (measured as the percentage change form resting to anxiety condition) and SA extends Friedman's *Neurovisceral integration model* to the competitive sport setting. This is in line with Parrado et al. (2010), who found a positive correlation between SA and LF/HF ratio, as previous studies have shown that LF/HF ratio behave in a similar way as fractal HR dynamics in conditions with reciprocal changes in sympathetic and vagal outflow (Hautala et al. 2003; Mourot et al. 2007; Tulppo et al. 2005).

Our second main purpose was to explore how perceived state anxiety and HR dynamics may evolve during a second consecutive day of real competition. No studies, to the best of our knowledge, had previously examined this issue. Results showed that while both SA and CA significantly slowed down from aC_1 to aC_2, any HR dynamics indices, except from RRi, significantly differed from aC_1 to $aC_{2.}$ Moreover, the abovementioned correlation between α_1 and SA in C_1 was lost in $C_{2.}$ Interestingly, it has been already showed that higher levels of competitive experience (i.e., number of years at elite level) are related to lower intensities of pre-competitive perceived trait anxiety (Mellalieu et al. 2004). The repetitive exposure to precompetitive pressure may reduce the suspense involving success in the task, and therefore diminish the flee response. At the same time, pre-competitive anxiety is known to be also influenced by athletes' familiarity with a specific competition setting (i.e., *timing* and place of the competition) (Cerin et al. 2000). Hence, it could be possible that pre-exposure to competition had acted during C_2 as a buffer to reduce both SA and CA, despite anxiety-related vagal activity still remained withdrew, as evidenced by persistently altered HR dynamics.

Concomitantly, although not statistically significantly, SC increased from aC_1 to aC_2 and probably contributed to further decrease the intensity level by which anxiety symptoms were perceived (Lundqvist et al. 2010). Meanwhile, the large and significant correlation found in aC_1 between SA and CA ($r = 0.711$, $p < 0.05$) get lost in $aC_{2,}$ thus suggesting a different evolution pattern for each of three components of CSAI-2R after repeated exposure to competitive pressure (i.e., C_2 condition) (see Fig. 2). Besides it should be noted that a nearly significant positive correlation ($r = 0.603$; $p = 0.065$) between CA and SampEn emerged during C_2. In summary, our combined psycho-physiological approach coincide in the idea that somatic and cognitive subscales of CSAI-2R assess different components of anxiety, and probably are related to different cardiac autonomic responses or patterns. Notwithstanding, future research with larger samples should clarify these relationships between HR dynamics fractality and regularity, on one hand, and somatic and cognitive anxiety, on the other hand. Especially, what it concerns to the dynamical behavior of the aforementioned associations in regard to competitive experience acquired.

Limitations

One limitation of this study is the subject population. Sample size was small ($n = 11$) and unfortunately five participants could not be tested of the baseline HR dynamics in the training condition, which may limit the ability to generalize results. However, the elite level of individuals is relevant, and it may be argued that our results should be even further exaggerated in novice or amateur athletes, as competitive experience is known to buffer precompetitive anxiety responses (Mellalieu et al. 2004). A second limitation may be the employment of Polar HR monitors instead of ECG recordings to estimate RR intervals, as possible physiological artifacts, such as ectopic beats or arrhythmic events, are more difficult to detect. Notwithstanding, this instrument has been previously validated for the measurement of RR intervals and subsequent HR dynamics analysis (Gamelin et al. 2006; Nunan et al. 2009) and even has been proposed to be interchangeably used with ambulatory ECGs (Weippert et al. 2010). Indeed, some recent investigations dealing with nonlinear methods have used it to acquire RR data (Karavirta et al. 2009; Vanderlei et al. 2010).

Conclusions

In summary, the major outcomes of this investigation were: (1) pre-competitive anxiety induced by a real BMX competition significantly unbalance HR dynamics towards a slowing down vagal control, as evidenced by significantly reduced both temporal (RRi, SDNN and *r*MSSD) and spectral domain (lnLF and lnHF) indices of HRV; concomitant with a reciprocal enhancement of sympathetic activity, as evidenced by an increase in LF/HF ratio. This was further confirmed by altered HR regularity and fractality (SampEn and α_1) towards an increasingly regular and strongly correlated signal. (2) Moreover, α_1 kept a positive relationship with the level of SA perception in the first exposure to competitive pressure, in line with Friedman *Neurovisceral integration model* (Friedman 2007); therefore, higher levels of perceived SA were related to a *brownian noise* scaling structure of HR dynamics, characteristic of vagal withdrawal (Hautala et al. 2003; Penttila et al. 2003). (3) A repeated exposure to competitive stress enables a greater familiarity with a specific competition setting (i.e., *timing* and place of the competition), thus possibly diminishing *flee* response and acting as a buffer to reduce subjective anxiety perception (i.e., decreasing SA and CA and increasing SC scores of CSAI-2R). (4) SA and CA components of anxiety behave differently than SC component, both when psychologically and physiologically analyzed. (4) In summary, HRV analysis seems to provide an individual, practical and complementary tool to assess competitive pressure, what may be useful for coaches to handle with this key factor in sports performance, leading to its improvement and the setting of the IZOF (Hanin 2000, 2003) without an excessive recurrence of inventory techniques. Moreover, HRV analysis should help in designing strategies aimed at optimizing the impact of precompetitive anxiety on BMX performance, as previously suggested for other sports (Cervantes Blásquez et al. 2009; Cooke et al. 2010).

Moreover, this research complies with the Spanish laws and the Declaration of Helsinki, and has been approved by the Ethics Committee of the University of Valencia.

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